Pulsed Plasma Jet Actuators for SWBLI Control:

Summary Slides for 2016 SBLI Meeting

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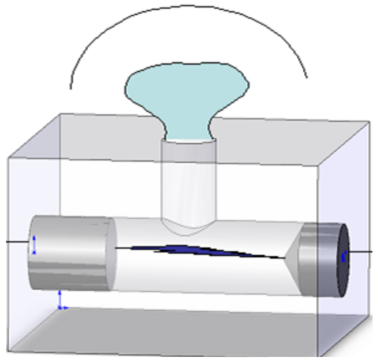
Outline

- Brief Phase II Summary Slides
- UofM Testing Detail

Phase II Project Summary

Project Objective and Approach

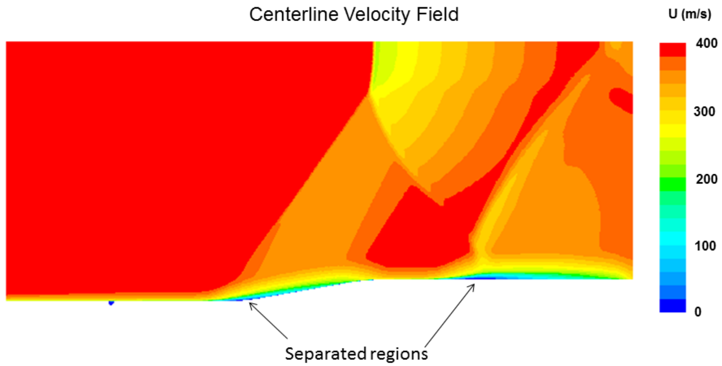
- **Project objective: develop pulsed plasma jet actuators for active control of SBLIs**
  - Synthetic jet formed by electric arc in a cavity
  - Potential for high frequency pulsing (kHz) and high velocity jets (hundreds of m/s)

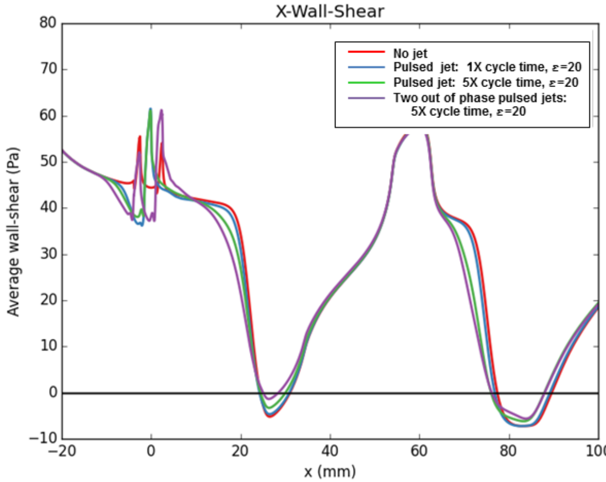


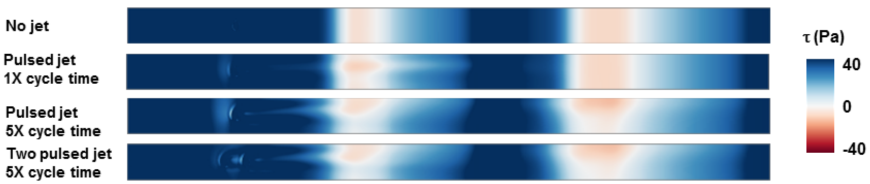
- **Phase I – Some success reducing SBLI separation sizes with actuators**
- **Phase II – Refined actuator design and measured effects**
  - CFD simulations to improve understanding of actuator operation and guide design changes
  - Actuator hardware and drive electronics development
  - Actuator testing in a variety of SBLI flowfields

CFD Results

- **Actuators generally have a relatively weak effect on the supersonic crossflows of interest**
- **It is important to maximize the jet momentum/energy**
  - **Momentum ratios for the plasma jets are generally low (J< 0.5 for a Mach 1.5 crossflow)**
  - **Difficult to maximize because gas heating efficiency goes down as pulse energy goes up**
- **Pitched only jets can have a strong local benefit, but the effect decays quickly in time and space**
  - **Lower portion of the boundary layer improved through direct momentum addition and vortex generation (V-G)**
- **Skewed jets can create a V-G benefit far downstream (>50 d_{jet})**
  - **Jet needs a sufficiently long discharge time**
  - **Time averaged/cycle averaged benefit is small**

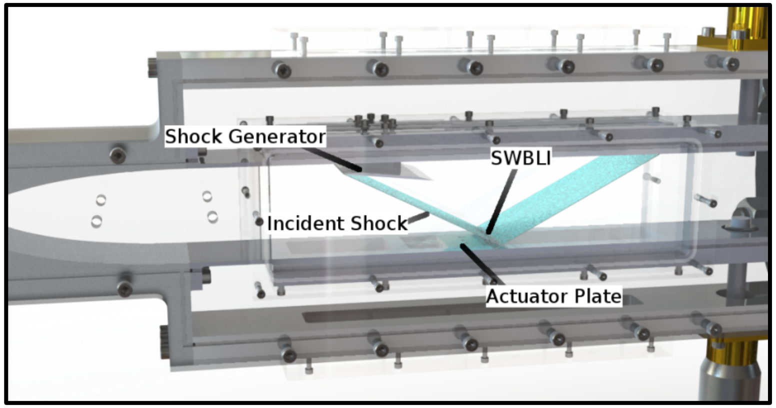




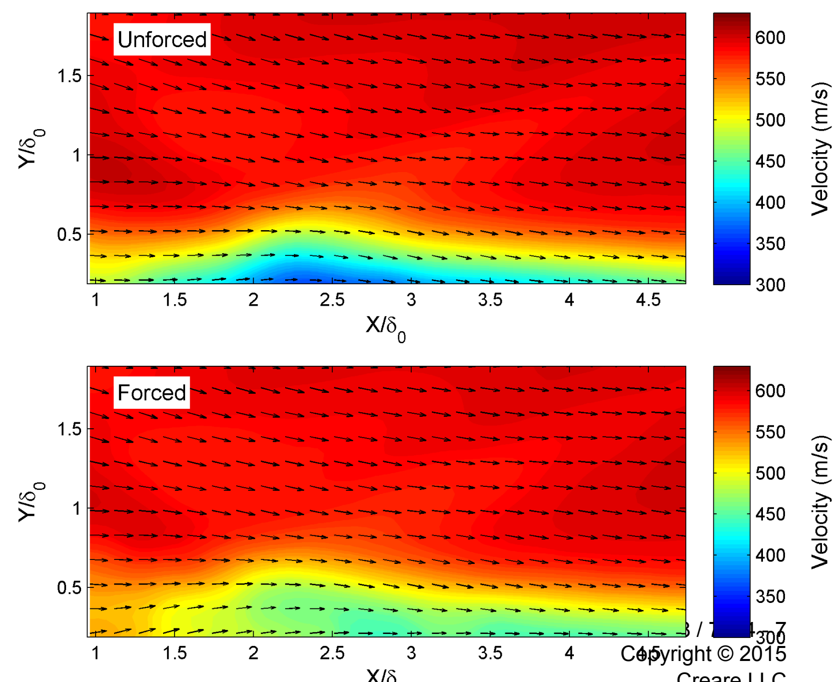


Single SBLI Interaction Testing

- **Testing was performed in the UofT Mach 3 wind tunnel**
  - Reflected shock SBLI, compression ramp SBLI, and clean crossflow tested
- **Oil streak visualization**
  - Small local reductions in SBLI separation size with forcing
  - Span averaged impact was minimal
- **PIV – Time averaged**
  - Presence of jet holes affected boundary layer without forcing
  - Small velocity increase in the lower portion of the boundary layer with forcing
  - Positive effect confined to small region (< 20 mm, < 3.8 δ_0 downstream of actuator)
- **Downstream pitot profiles**
  - Forcing has no effect from 35 mm (6.6 δ_0) downstream
  - Forcing has little to no effect 12 mm (2.3 δ_0) downstream



Mid – Jet Plane



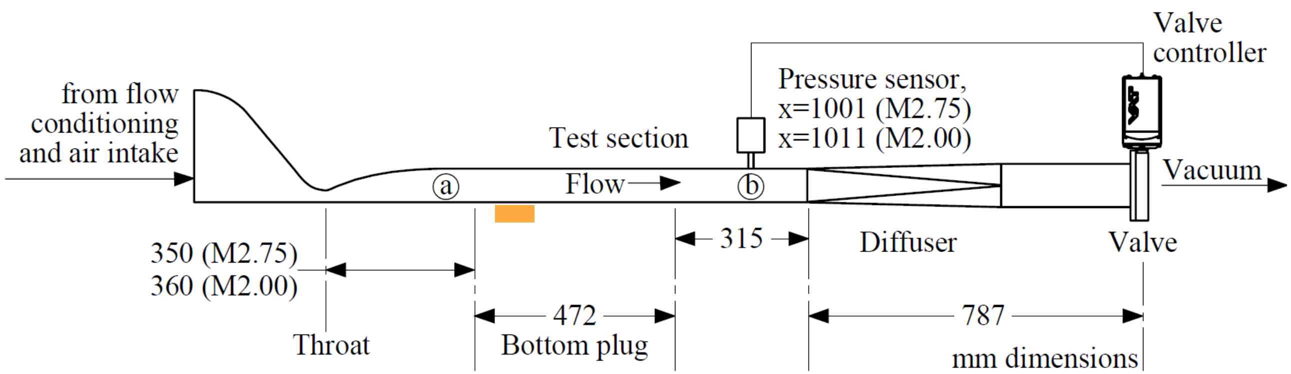
Overall Phase II Conclusions

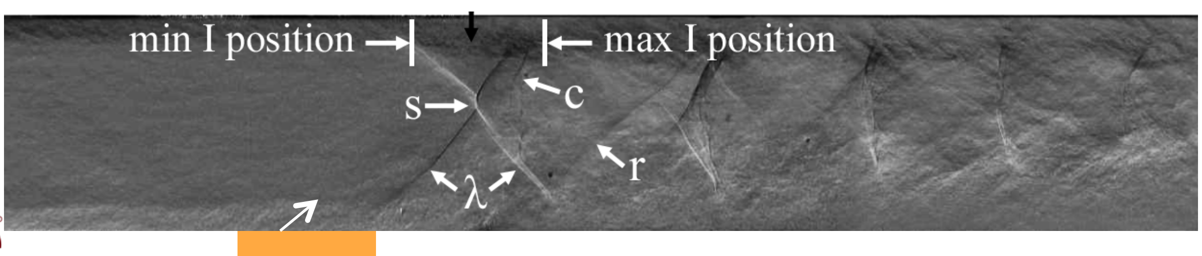
- **Pulse plasma actuators can provide some benefit for controlling SBLI flow fields**
  - Increased velocity in the lower portion of the boundary layer from vortex generation and/or direct momentum addition
- **Effect of the current actuators is too weak to be of practical use for flow control**
- **Suggested directions for future work on pulsed plasma jet actuators**
  - Methods to maximize (and quantify) the jet momentum/energy
  - Use of the actuators in less energetic flows:
    - » Separation control on subsonic airfoils / inlets

UofM Testing Detail

Backpressure Shock Train Testing

- **Tested plasma actuators in a scramjet isolator simulator**
  - Backpressure driven shock train in constant area duct (2.25x2.75")
  - Mach 2.0 inlet – transitional shock train
- **Only bottom wall controlled with actuator due to tunnel access**
  - Thicker b.l., larger separation on bottom wall, likely more important to control
- **Goal: Determine effect on shock train length and dynamics**
  - Reduction of shock train length or dynamics would be benefit for unstart control
  - Acquired high speed schlieren movies and pressure measurements

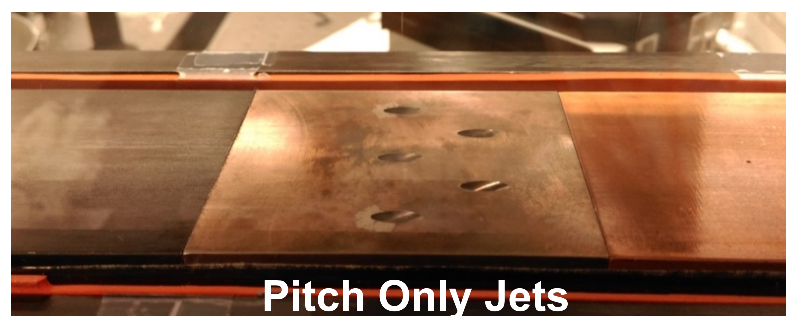




Actuator Geometry

- **Two jet geometries designed with input from CFD studies**
  - **Skewed jets: long discharge duration (~300 us) shown to be beneficial from CFD**
  - **Pitch only jets: large orifice, shorter discharge. Potential benefit very close to jets.**
- **Two rows of jets fired out of phase**
  - **Only used both rows for first test series due to electronics failure**

Actuator Geometries for UofM Testing						
Array Name	Orifice Diameter	Jet Centerline Spacing	Pitch Angle	Skew Angle	Number of Orifices per Cavity	Estimated Max Forcing Frequency
Skewed Jets	1.6 mm	9.5 mm	40°	-90°, 90°	2	850 Hz
Pitch Only Jets	3.2 mm	19 mm	22°	0°	1	1900 Hz

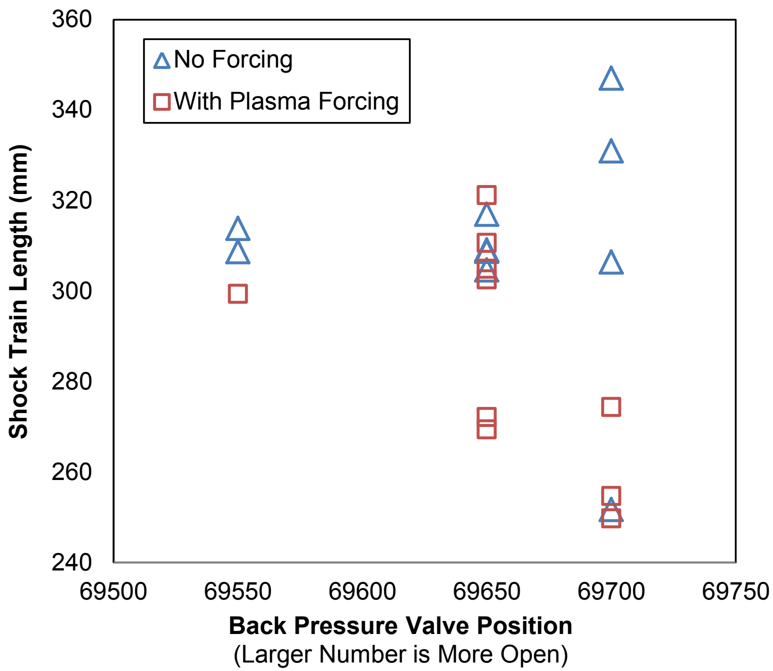


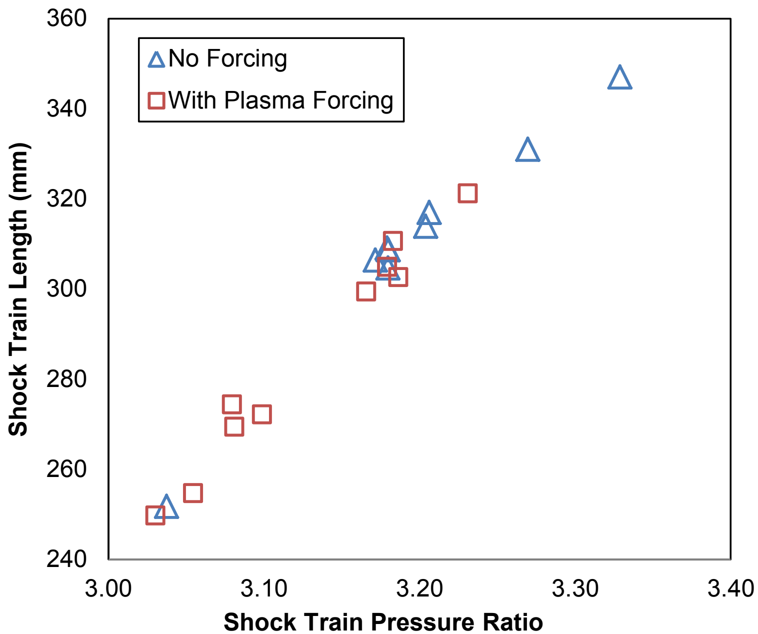
Test Summary

- **Test series 1: skewed jets**
  - Tested actuator effect on previously established shock train
  - No effect found on length, pressure rise, or unsteadiness for range of shock train locations, actuator forcing parameters
- **Test series 2: skewed jets**
  - Turned actuator on before setting backpressure valve and establishing shock train
  - At first forcing appeared to prevent upstream movement of shock train
  - Further examination suggests any effect may have been due to run-to-run variations
- **Test series 3: skewed jets**
  - Periodic movement of backpressure valve with actuator on and off
  - No impact from actuator on speed or magnitude of movement
- **Test series 4: pitch only jets**
  - Repeat select data from test series 1-3
  - No clear effect from actuators

Actuator On Before Valve Details

- **Completed several back to back runs with actuators on and off at different backpressure valve positions**
- **Runs with the actuator on were generally had a shorter shock train**
  - **Significant run to run variation in the shock train length**
- **If plotting length vs pressure ratio, all data falls on the same line**
- **Source of run-to-run variability not clear, may be some benefit from actuator forcing**





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Actuator Movie Examples

- Quiescent flow – pitched actuator – 20 kfps
- Quiescent flow – skewed actuator – 20 kfps
- Pitch Jets Actuator with Shock Train – 20 kfps
- Skewed Jets Actuator On/Off Before Valve Comparison
  - Valve position = 69700
  - Run 313 with forcing – short shock train
  - Run 314 no forcing – longer shock train

Shock Train Position (Shock Intersection S) vs Time For Runs with and without Forcing. Back Pressure Valve Closed at 1000 ms